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HALLEY'S COMET EXPLORATION AND THE JAPANESE USUDA LARGE ANTENNA

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16. Abstract

An overview of the Japanese PLANET-A project to investigate Halley's Comet is given. The objectives and scientific challenges involved in the project are given, and the nature of the contribution made by the large antenna array located at Usuda-Cho, Nagano Prefecture Japan is discussed. The structural design of the MS-T5 and PLANET-A probes are given, as well as the tracking and control network for the probes. The construction, design, operating system and site selection for the Usuda antenna station are discussed.

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1. FOREWORD

Halley's comet is coming back in early 1986 after the lapse of 76 years. A project to send a satellite to the comet and take pictures of the comet from extremely close distance is being planned by National Space Science Research Center. This project is called the PLANET-A since this is the first endeavor of the inter-planet flight project in this country.

It is assumed that planets and comets are made of the same substances.

While the planets have made considerable changes compared to their original shape and condition through their natural evolution, comets have shown little or no changes because (1) comets have spent most of their time outside the boundary of the solar system, and (2) the relatively small size of the comets prevents the gravity from affecting the interior structure of the comets. In addition, as the comets approach the sun, the surface layer of the comets is blown away, and the outer layer is kept relatively fresh at all times. Many of these short cycled comets, unless they belong to the class of the super comets, lose volatile matters and turn inactive as they come near the sun repeatedly. Some of the comets which belong to the class of long cycle can not be observed because their orbit cannot be estimated if only one appearance has been recorded in history. It is possible to calculate and establish a definitive orbit for Halley's comet unlike the type of comets that was mentioned above. In addition, Halley's comet is an active comet full of volatile matters. That is why this is an excellent chance to examine the comet.

Japan has launched a number of scientific satellites in the past. It is understood that Japan has adequate technology in rocketry and design of payloads. Yet, this mission has added problems - a need to determine more accurate orbit and the requirement for extremely long range communication. This essay concerning the subject of Halley's comet exploration attempts to introduce the general outline of the PLANET-A project as well as moves being made by other nations in the world. At the same time, a large antenna which is being built at Usuda-Cho in Nagano Prefecture in support of the PLANET-A project will also be introduced.

2. ORBIT OF HALLEY'S COMET AND THE HISTORY OF OBSERVATION

Generally speaking, comets are named after the person who first discovered them. Halley's comet is the exception. It was named after the British astronomer Edmond Halley (1656 - 1742) who predicted the return of the comet after discovering that the movement of the comet was periodical. The movement of comets fascinated astronomers in those days. For example, Kepler stated that the comet of 1607 (it turned out to be Halley's comet) was making a linear movement after careful observation. Halley, Newton's closest friend, applied Newton's method in order to estimate the orbit of 24 comets which were observed with excellent results. Among these 24 comets, Halley concluded that the ones observed in 1531, 1607 and 1682 were the same comet. Halley went one step further by predicting that the comet would come back in 1758. His prediction was proven to be correct after his death. The orbit of comets gradually change as they come near planets within the solar system or by the jet effect of gushing gas. Through the formulation of a model of these effects and by conducting an inverse operation, it is known at this time that Halley's comet which was first recorded in 240 BC returned approximately thirty times so far.

Tab. 1 Orbital element of Halley's comet

Perihelion	0.5871 AU
Eccentricity	0.9673
Orbital angle	162.24 deg
Perihelion, angle	111.85 "
An ascending node longtitude	58.15 "
Date, passing perihelion	1986. 2. 9

Tab. 1 shows the orbital element of Halley's comet. It has the cycle of approximately 76 years. Its perihelion is inside the orbit of Venus, and its aphelion is outside the orbit of Neptune. The orbital angle is approximately 162 degrees, which means that the angle formed by the orbital plane and the plane of the ecliptic is 18 degrees, a relatively high figure, and that the direction of its movement is opposite to that of planets within the solar system. The above facts provide the Halley mission with the following restrictions.

(1) The relative speed at the time of the meeting of the probe and the comet becomes extremely high (-70 Km/s). Accordingly, the time that the probe is allowed to spend in the vicinity of the comet becomes short. In addition, the question of how to protect the probe from the dust and other particles when the probe is at the position extremely close to the comet must be solved.

(2) The meeting point is limited to the ascending node where the comet goes across the plane of the ecliptic and the vicinity of the descending node. Otherwise, the orbit of the probe must be set away from the plane of the exliptic requiring tremendous energy for launching the probe. This is why meeting time of the probes from many nations is concentrated during the early part of March 1986 when the comet moves across the plane of the ecliptic from north to south.

3. THE EXPLORATION PROJECT OF HALLEY'S COMET

3.1 Response of other nations

At present, Japan as well as ESA (European Space Agency) and USSR are planning to send a probe to explore

Halley's comet. The project of ESA is called Giotto, a spin stabilized satellite. Besides the project of photo taking using a camera, mass analysis and other on site data gathering are planned in this project. It is expected to fly by the core of the comet at the distance of 500 Km. Its launching is scheduled in the summer of 1985. USSR originally planned to send an orbiter and a balloon to Venus jointly with France. Later, the original plan was changed, and a new plan called Venera-Halley was established. This project will be assisted by east and west European scientists under the project name Intercosmos. The probe is structured under the tri-axes control system. The ratio of remotely controlled data gathering and direct data gathering is said to be 50 - 50. It is expected to fly by the core of the comet at the distance of 10,000 Km. Two sets of probes are launched within 1984 and head toward the comet via Venus in June 1985. The time of the meeting with the comet by Giotto and Venera-Halley is during the early period of March 1986 as explained above.

Although USA is not planning to launch a satellite exclusively for the exploration of the Halley's comet, the NASA will use ISEE-3 (International Sun Earth Explorer) to first explore the Jacobini-Zinner comet by shifting the satellite from the present stationary location. Then, the satellite which is renamed the ICE (International Cometary Explorer) will approach the Halley's comet within the distance of 30 million Km in order to gather data.

Japan's PLANET-A will be launched off Uchinoura, Kagoshima in August 1985. As shown in Fig. 1, it will go around the sun about 3/4 revolution before meeting with the comet in early March. Its primary objective is to take remotely controlled pictures of the comet within the environment of vacuum ultraviolet. Accordingly, there is no strong need to come extremely close to the comet. It is tentatively planned to let the probe fly by the comet at the distance of a few hundred thousand Km. Prior to the launching of the PLANET-A, Japan is planning to launch a test probe MS-T5 for the purpose of rehearsing the launching as well as other proceeding. If everything goes well, the probe of the MS-T5 will come within five million Km of the comet in early March along with the probe of the PLANET-A.

For the purpose of bringing about the international cooperation and maximizing the effectiveness of the exploration by each participating nation, an international organization called IACG (Inter-Agency Consultative Group) consisting of NASA, Russian Academy of Science, ESA and ISAS was formed. It is expected to instill international cooperation in coordination with IHW (International Halley Watch), an organization to observe the comet from the ground.

3.2 General outline of MS-T5 and PLANET-A

Photo 1 shows the external appearance of MS-T5. The cylindrical probe is 0.7 m high and 1.4 m in diameter. An antenna, 80 cm in diameter, is set up facing toward the front. The primary objective of MS-T5 is to insure that the launching operation goes without difficulty. Its secondary objectives are to rehearse other items such as the attitude control system, orbit control system... etc.

The structure of the probe of MS-T5 is identical to that of PLANET-A except that some of the data gathering instruments are not present in MS-T5. The most important instrument in PLANET-A is the Liman Alpha Photographic Equipment which takes the pictures of the huge hydrogen cloud surrounding the Halley's comet within the environment of vacuum ultraviolet.

Tab. 2 describes the structural organization of MS-T5 and PLANET-A. As shown in Tab. 2, MS-T5 also has some scientific instruments on board. The attitude control system of the two probes is the spin stabilization system.

Tracking of these probes is done by Usuda Space Observation Post (hereinafter referred to as Usuda station) equipped with a 64 meter antenna. At the early stage of launching, however, a network consisting of Kagoshima Space Observatory, Katsuura Tracking Station of the National Space Development Agency and Usuda Station will jointly conduct the tracking. In addition, NASA's tracking network has been requested to provide some assistance. Fig. 2 shows the overall network of the tracking.

MS-TS and COMET-A are controlled according to the following schedule after launch. As soon as these probes enter the orbit to escape the earth's gravity, they enter approximately five hours of blind area (from Japan). During the five blind hours, gas jet is automatically activated in order to reduce the spin of the probes from 120 rpm to 30 rpm. At the same time, the axis of the spin is adjusted perpendicular to the direction of the sun. (These two motions are effected by a timer.) At the second visible condition, the spin is further reduced to 6 rpm, and the axis of the spin to adjusted perpendicular to the plane of the ecliptic. The use of the antenna is started. Four or five days after the launching, the orbit of these probes is corrected at the command of the Usuda station, an the probes are headed toward the comet. As the probe of PLANET-A takes the photograph of the comet, the spin rate is reduced to 0.2 rpm by activating the momentum wheel.

4. USUDA LARGE SIZE ANTENNA

4.1 Ground station for the exploration of deep space and its design

Ground station for the exploration of deep space must be able to maintain communication with a probe which is extremely far away from the earth. Therefore, a large size antenna must be structured at a location away from the city noise.(1)

The construction of the Usuda station was advanced practically parallel to the preparation for the PLANET-A (and MS-T5). Fig. 3 shows the flow chart of the design and the design process of Usuda station. Since the use of S band (2.1 - 2.3 GHz) was determined in PLANET-A ("as well as MS-T5" is hereinafter omitted.), it was estimated at the early stage of structuring the ground station that the system noise temperature at this frequency band would be 50 K (antenna noise temperature, 33 K; low noise amplifier, 10 K; miscellaneous city noise, 7 K) and the antenna opening efficiency would be 70 %. After that, as the design of the communication system was advanced, it became apparent that a large size antenna, more than 64 meters in diameter, was required at the ground station.

The operating system of the ground station is directly connected to that of the probes. Therefore, the development of the systems design of the ground station was advanced in parallel to or directly connected to that of the probes.

4.2 Selection of the site

The following conditions were given to the selection process of the site before Usuda-Cho was selected: (1) Lowest level of city noise and no interference with public microwave circuitry, (2) No power-transmission lines in the vicinity, (3) Away from commercial air transportation routes, (4) State owned land, (5) Local support and cooperation can be obtained, (6) Excellent surface transportation necessary for the construction project.

It took almost two years, 1980 to 1982, for the site selection. During this period, actual measuring of city noise by the level of noise and the type of noise makers (eg. automobiles, arc welding machines, DC motors...etc.) have been compiled in order to determine the required distance from the origin of these noises. On the subject of the possible interference by the public microwave circuitry, assistance was obtained from Ministry of Posts and Telecommunications, Nippon Telephone and Telegraph Public Corporation, KDD and others. Assistance was also provided by Forestry Agency, Nagano Prefecture Forestry Bureau, Usuda District Forestry Bureau and the city of Usuda.

4.3 Design of Usuda large size antenna

The Usuda large size antenna is a Kaseguren* antenna of beam feeding system. The diameter of the main reflective mirror is 64 meters. Fig. 4 shows the antenna and its attachments.

The main reflective mirror aims to attain the accuracy of 2 mm rms and is designed to enable the use of up to X band. Since large size reflective mirrors cause distortion caused by their own weight, designing technique based on the homology concept(2) has been introduced. In other words, in spite of the fact that the surface of the mirror develops structural fluctuation based upon an angle of elevation (El angle), the light passage length is constantly maintained at a fixed level by controlling the position and the gradient of the supplementary reflective mirror according to the changes made to the El angle.

The beam feeding system is widely applied to large size antennas in recent years. Light beams are transmitted through the use of several reflective mirrors, and temporary radiators or low noise amplifiers and other instruments are established on the ground where there is no El rotation. Usuda large size antenna takes the beam feeding system(2) of the four reflective panel structure (#1 - #4 of Fig. 4). #1 and #2 are placed on the El rotational axis. #1 rotates along with the El rotation of the main reflective mirror, but #2 - #4 do not receive El rotation. In Fig. 4, the temporary radiator is placed at the area shown in dotted lines, and by placing the reflective panel #4 facing the radiator, an ordinary four reflective panel structure is formed. However, in Usuda large size antenna, the area of the dotted lines was left alone as the future expansion area (for exclusive receiving purpose only for low noise), and the reflective panel #5 was attached. The beam feeding system is designed for the use of both S band (2.1 - 2.3 GHz) and X band (7.1 - 8.6 GHz).

The antenna makes its revolution as a whole toward the direction of an azimuth (Az angle). In other words, the three story building with the sign antenna and antenna instrument room in Fig. 4 is supported by the wheels positioned at the base area, and the wheels are placed over the rail. The master collimator shown in the figure is the device to measure the direction of the main reflective mirror. It is placed on top of the tower (which does not engage in Az rotation) that is built independent of the antenna structure. The master collimator is an optical angle detection device. It measures the El angle and Az angle by attaching a mirror at the back of the main reflective mirror.

The beam width of the antenna is extremely narrow (approximately 0.14 degrees at 2.1 GHz; 0.034 degrees at 8.5 GHz), and its driving is accomplished by the programmed control. Incidentally, the automatic tracking function that can be used when the signal is extremely strong is also added.

The temporary radiator is a cone shaped colgate horn exclusively for S band. The feeding device is also for S band, but it can be used for both transmitting and receiving. A high power amplifier (HPA) of S band and two low noise amplifier (LNA-1 and LNA-2) are connected to the feeding device. The HPA is capable of continuously transmitting the maximum 40 kW. The LNA-1 is a helium gas cooled parametric amplifier whose noise temperature is about 8 K (at 2.3 GHz). The feeding device has two couplers that have two modes, TE 01 and TM 01, and it is capable of extracting angle error signal for automatic tracking. The angle error signal is amplified by the LNA-2 (FET amplifier, noise temperature 80 K). Although X band is not in use in the PLANET-A project, the parts below the colgate horn can be changed if transmission via X band becomes necessary in he future.

The central position of the antenna (the point where the El axis and the Az axis cross over) is 36 degrees 07' 45" 310 North, 138 degrees 21' 57" 192 East and altitude 1,489.60 m.

5. FUTURE PLANS

Exploration of Halley's comet opens up the new route of the space science research using satellite in this country. The Halley mission has enabled us to discuss and argue as the practical matters about the future space mission aimed mainly at moon and planets within the solar system. For example, the Space Science Research Center has proposed the unmanned moon swing by project as a part of the future space exploration projects.

The Usuda large size antenna will play an important role in the future space missions. But the use of the large size antenna does not stop here. As the volume of data transmission increases between scientific satellites and ground stations, communication system for satellites with extreme elliptical orbit which requires large size antennas as prerequisite is being discussed.

Not many large size antennas in the world measure as much as 64 meters in diameter. Therefore, the one in Usuda station can be effectively used for radio astronomy, observation and research of radio science and related fields. Particularly, the structure of the VLB(4) (Very Long Baseline) network with other antennas in the world will become extremely meaningful.

International attention is being paid to the Usuda large size antenna. For example, NASA has indicated some interest in the future assistance in tracking and communicating with its satellites. An official request has been received concerning the ICE support.

6. CONCLUSION

A project called PLANET-A is presently being advanced by the Space Science Research Center of Japan in order to explore Halley's comet. In this essay, the general outline of the PLANET-A project as well as the large size antenna which is being constructed at Usuda-Cho, Nagano prefecture for the purpose of supporting the PLANET-A project are introduced.

In view of the launching of the probe next year, the

Space Science Research Center of Japan is presently concentrating its effort to prepare for the project. The construction of the Usuda large size antenna is showing a steady progress, and it is expected to be completed not later than October 31 this year. The author wishes to express the deepest appreciation for tremendous cooperation and support provided by agencies concerned as well as private citizens. In closing this essay, the author wishes continued support and assistance provided by agencies concerned as well as private citizens.

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Fig. 1 The orbit of PLANET-A and MS-T5

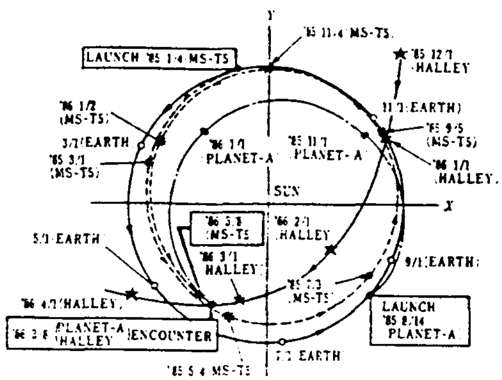

図 1 PLANET-A と MS-T5 の軌道

Tab. 2 Primary structural element of PLANET-A and MS-T5

Electric system:

solar battery - Si BSF type 70 - 100 W

Secondary battery - Ni-Cd, 2 AH x 15

Ignition electric source - Capacity recharge system

Communication system (RF):

Low gain antenna - Cross dye pole

Med. gain antenna - 3 elem linear alley

High gain antenna - off set parab.

Disban. motor - DC two phase

Telemetry transmitter - S band, 70mW/5W,PCM/PSK/PM

Command receiver - S band, PCM/PSK/PM

Distance device - S band RARR

Communication system (Data):

Data management unit - coded PCM, 64BPS

Command decoder - separate, programable, block

Data recorder - magnetic pulse, 1 Mb

Interior environmental detection - 64 items, 1/32s, 1/1024s

Timers - electronic, ignition, termination, switching channel

Control system:

momentum wheel - 2,000 rpm, 20 Nms

Wheel drive device - DC motor

Control circuit - Thruster, wheel control, attitude data management

Solar sensor - view field: the plane of ecliptic, +- 85 deg., gray code

Star scanner - V-shaped Si photodiode

New tension damper - Silicon oil sealed ring

Propulsion system - Attitude control, orbital control

Propellant - Hydrazine

Structural thermal control:

Structure - CFRP

Thermal * - Bimetal

Thermal blanket - Al evaporation

Observation system (MS-T5):

Plasma wave observation device - Expandable, 10 m antenna 2, 70 Hz to 200 kHz electric field search coil, 70 Hz to 4 kHz, mag. field

Inter planet space magnetic field observation device - Ring core type flux gate magnetic gage

Observation system (PLANET-A):

Liman alpha photographing device - UV image intensifier CCD

Spin synchronous shift integrating system

Solar wind observation device - Electron • ion 3 D speed distr.

30 eV to 16 KeV

Photo 1 Probe MS-T5

写真 1 探査機 MS-T5

Fig. 2 MS-T5 / PLANET-A tracking network

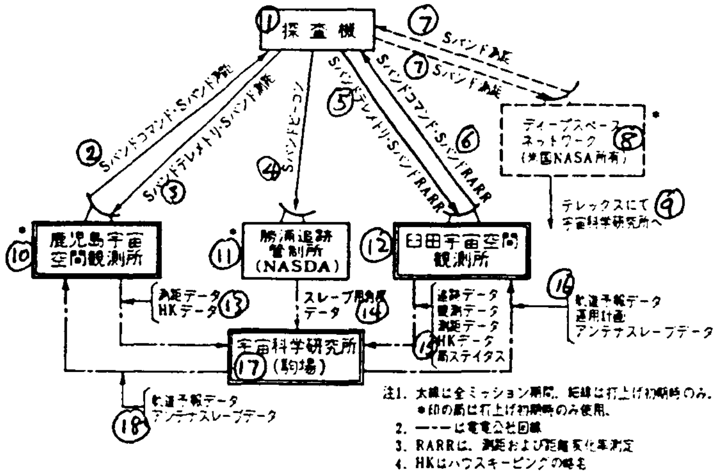

図 2 MS-T5/PLANET-A 追跡ネットワーク

Key list:

1. probe 2. S band command, S band distance 3. S band telemetry, S band distance 4. S band beacon 5. S band telemetry, S band RARR 6. S band command, S band RARR 7. S band distance 8. Davis Base Network (possessed by US, NASA) 9. to Space Science Research Center via Telex 10. Kagoshima Space Observation Center 11. Katsuura Tracking Station 12. Usuda Space Observation Station 13. distance data, HK data 14. angle data for slave 15. tracking data, observation data, distance data, HK data, status of the station 16. orbital forecast data, operational plan, antenna slave data 17. Space Science Research Center (Komaba) 18. Orbital forecast data, antenna slave data

Note 1. Thick lines indicates the duration of the entire mission; thin lines indicate only during the early stage of the launching. Stations marked by * are used only at the early stage of the launching.

Note 2. — - — indicates the circuit of Japan Telephone and

Telegraph Agency.

Note 3. RARR indicates the measurement of the distance and the distance change ration.

Note 4. HK indicates house keeping.

Fig. 3 Designing process of the ground station

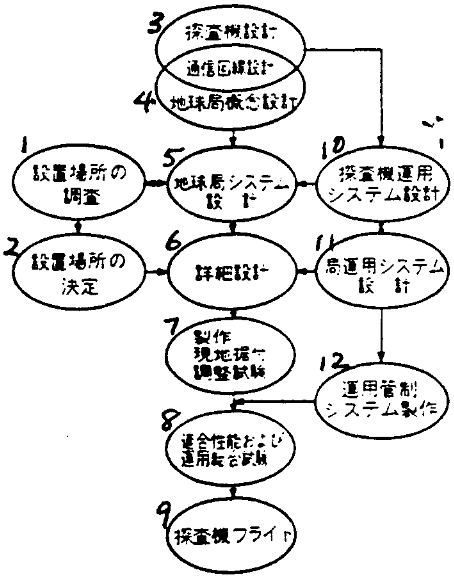

図 3 地球局設計・製作過程

Key list:

1. examination of the site 2. determination of the site
3. design of the probe 4. design of communication circuitry
5. design of ground station system 6. detailed design 7. production, installation at the site, testing 8. suitability test and other operational tests 9. flight of the probe
10. design of the probe operating system 11. design of the station operating system 12. production of the operational control system

Fig. 4 Structure of the antenna

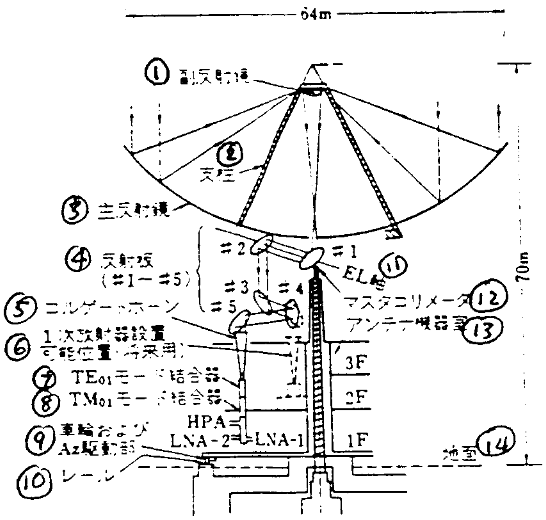

図 4 アンテナの構成

Key list:

1. the supplementary reflective mirror 2. a support beam 3. the main reflective mirror 4. reflective panel(s) 5. colgate horn 6. a possible area to set the temporary radiator (for the future) 7. TE 01 mode coupler 8. TM 01 mode coupler 9. wheels and Az drive part 10. a rail 11. EL axis 12. a master collimator 13. an antenna instrument room 14. ground